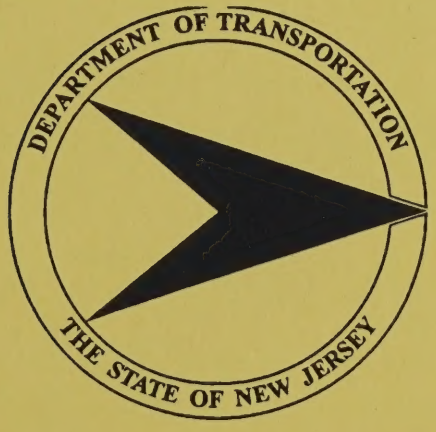
FHWA/ NJ 97-010
7730

Cost Effective Rehabilitation and Drainage Techniques for Pavements

Final Report
by

Victor E. Mottola, P.E.
and
Gerald J. Kauffman, P.E.



Prepared by
New Jersey department of Transportation
Quality Assurance, Improvement, and Research
In Cooperation With
U.S. Department of Transportation
Federal Highway Administration

NJ
TE
215
M68
1997
C.1

Disclaimer Statement

The contents of this report reflect the views of the author(s) who is (are) responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the New Jersey Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

NJ
TE
215
M68
1997

c.1

ACKNOWLEDGMENTS

The authors wish to express their appreciation to those individuals who have provided assistance and advice needed to complete this work.

Appreciation is expressed to Mr. Bob Stewart, the Resident Engineer for his interest and help and without whose cooperation our job would have been impossible.

Thanks also go to Messrs. Tony Chmiel, John Salt, Ken Jaslar and Bill Whitfield of our Research staff who took samples, ran tests and collected and analyzed data.

TABLE OF CONTENTS

	PAGE
A. OBJECTIVE	6
B. BACKGROUND	6
C. PRELIMINARY INVESTIGATION	9
D. PRECONSTRUCTION CONDITION OF I-295 ROADWAY ..	13
E. CPR CONSTRUCTION	17
F. ALKALI-SILICA REACTION	34
G. POST-CONSTRUCTION EVALUATION	34
H. ECONOMICS	39
I. CONCLUSIONS	41
J. RECOMMENDATIONS	42

INDEX OF TABLES

		PAGE
TABLE 1	Pavement Distresses and Suggested Remedies	7
TABLE 2	Extent of Slab Distress on Rt. I-295	13
TABLE 3	Pre-construction Ride Quality	14
TABLE 4	Pre-construction Joint Faulting	15
TABLE 5	Pre-construction Deflection Measurements	16
TABLE 6	Comparison of Pre and Post Construction Deflection Measurements along Subseal Areas	34
TABLE 7	Joint Efficiency - Rt. I-295	36

A. OBJECTIVE

The objective of this study was to evaluate the field performance and cost-effectiveness of several Concrete Pavement Restoration (CPR) techniques during a construction project along New Jersey Route I-295. In contrast to the contraction joint design constructed by the other 49 States in the U.S., New Jersey em ploys a unique, high performance concrete pavement design which includes an intricate transverse expansion joint system. This expansion joint design requires special CPR techniques which are solely unique to New Jersey concrete pavements. Several CPR techniques for rehabilitation of New Jersey expansion joint pavements including slab subsealing, full depth slab replacement, partial depth spall repair, joint cleaning and sealing, longitudinal underdrain installation, and diamond grinding were monitored during construction and evaluated for up to one year under traffic.

B. BACKGROUND

In New Jersey, many jointed reinforced concrete pavements (JRCP) constructed during the height of the interstate construction boom in the 1960's and early 1970's are approaching or have passed their expected 20 year design life. Several concrete pavements including I-78 in Warren and Hunterdon Counties, and I-295 in Gloucester and Burlington Counties have passed their 20 year design life and exhibit moderate to severe concrete pavement distress. The destructive combination of heavy truck loading, water induced pumping and erosion of the subbase, and temperature based expansion and contraction of slabs has caused deterioration of concrete pavements in the form of slab pumping, full depth slab cracking, expansion joint spalling, joint faulting, and slab settlement. These pavement distresses cause an obvious and significant decrease in ride quality and structural capacity which in turn compromises the safety and comfort of the motoring public.

In order to correct concrete pavement distress and restore ride quality to a safe and comfortable level, several rehabilitation techniques have been developed. A common corrective strategy and one most widely used in New Jersey in the past is to resurface the deteriorated concrete pavement with at least 6" of hot mix asphalt. The overlay provides for additional structural capacity with a smooth riding surface and satisfactory skid resistance. Resurfacing of concrete pavements with hot mix asphalt has been used with good success as described in NJDOT Research Study No. 7778 (Second Generation Overlays) provided that the old concrete pavement is properly patched, there is no slab pumping, and random reflective cracking of the overlay is controlled by use of the saw and seal technique.

While the hot mix asphalt overlay approach has been successful in the past and will certainly be used on future projects, there are many cases where the existing concrete concrete pavement is in reasonably good condition and concrete pavement restoration(CPR) techniques such as slab subsealing, full depth slab re placement, partial depth spall repair, joint cleaning and sealing, longitudinal underdrain installation, and pavement grinding may be used to restore the pavement to an acceptable quality.

Asphalt resurfacing is used when conditions warrant reopening to traffic concurrently or immediately after construction. However, the addition of several inches of asphalt has several geometric and drainage limitations. Resurfacing decreases bridge underclearances and curb heights, and requires raising of catch basins, manholes, and other road hardware. CPR restores the pavement to an acceptable condition without changing the geometry of the roadway.

The relationship between the types of concrete pavement distress, cause of distress, and suggested CPR technique is outlined in Table 1. All concrete pavement distresses are caused in part by heavy and frequent truck loading.

Table 1.
Pavement Distress, Cause and Suggested Remedies

Distress	Cause	Suggested CPR Work
Joint Faulting	* Erosion of subbase * Impermeable subbase * Expansion joint corrosion/seizure * Joint incompressible	* Subsealing with grout * Long. Underdrains * Replace expansion joint device * Clean and reseal joint * Diamond grinding
Full Depth Slab Cracking	* Subbase Erosion and voids * Joint siezure and incompressibles * Loss of slab support and settlement induced cracking	* Subsealing with grout * Replace expansion joint device * Replace slab full depth, entire or partial slab, install load transfer dowels
Slab Pumping	* Impermeable Subbase * Subbase erosion	* Long. Underdrains * Subsealing
Partial Depth Spalling	* Alkali-Aggragate Reaction * Restricted slab expansion	* Partial Depth Patch * Replace concrete full depth

The need for successful CPR techniques was emphasized by in formation from the 1987 New Jersey Department of Transportation, Pavement Management Priority List [1] which identified, through ARAN surface roughness measurements, approximately 86 centerline miles of interstate concrete pavement as potential 4R (Reconstruction, Rehabilitation, Resurfacing, and Restoration) candidates. It is projected that at least 30 to 50 miles of the candidate 4R projects will be selected for concrete pavement restoration within the next 5 years using techniques outlined in Table 1.

New Jersey employs a unique, high performance concrete pavement design consisting of highly intricate, transverse expansion joint system. This is in contrast to the contraction joint pavement design utilized by the 49 other States in the U.S. Conditions surveys indicate that New Jersey expansion joint concrete pavements have routinely lasted in excess of 30 years be fore rehabilitation is required. Contraction joint pavements in States adjacent to New Jersey have lasted about 15 years before rehabilitation was required. The expansion joint allows for normal slab movement due to annual and daily temperature changes and also accommodates migration of incompressibles into the joint thus allowing for the longer pavement life.

Since the New Jersey expansion joint is unique among highway departments in the U.S., special concrete pavement restoration techniques are required. Subsealing should be carefully accomplished so that the 3/4" expansion joint is not fouled with grout. Full depth slab replacement at transverse joints may require replacement of the dowels. Joint cleaning and sealing may be done with special care to waterproof the joint. Pavement grinding should be specially done so that the open joint is not damaged. This report will address the special CPR considerations when used on New Jersey expansion joint pavements.

The typical New Jersey concrete pavement constructed during the 1960's and early 1970's consists of two or three - 9" thick reinforced concrete lanes in each direction. Each lane is 12 ' wide with 3/4" transverse expansion joints spaced at 78'-2". The pavement slab is typically supported by 8" to 12" of gravel or crushed stone subbase conforming to 1961 NJDOT specification, Type 1A or 1B subbase with fines (material passing # 200 sieve) ranging from 0 - 7%. Temperature reinforcement is generally composed of welded steel wire fabric. Longitudinal wires are size # W10.5 spaced at 6" center to center. Transverse wires are size # W5.5 spaced at 12" center to center. The steel is placed at 3" below the slab surface. Type A transverse expansion joints consist of twelve - 1 1/4" dia. carbon steel dowels per 12" lane. Each dowel is 16 - 3/4" long and inserted at one end into a 10" long corrosion free, stainless steel sleeve. Joint filler is hot poured rubber asphalt conforming to AASHTO M-213.

This study was designed to evaluate the constructability, field performance, costs, and materials properties of various Concrete Pavement Restoration (CPR) techniques used on a construction project along I-295 in Burlington County, New Jersey. These CPR strategies include slab subsealing, full depth slab re placement, partial depth spall repair, joint cleaning and sealing, longitudinal underdrain installation, and pavement grinding. CPR techniques were monitored during construction and field performance was evaluated for up to one year of service under traffic in order to determine the effectiveness of each rehabilitation strategy.

C. PRELIMINARY INVESTIGATION

Concrete pavement restoration was performed along I-295, Section 3K, 4K, 5K located between Mount Holly-Burlington Road (County Route 541) and Bordentown (US Route 130) during 1988 and 1989.

Plans and specifications for the rehabilitation of I-295, Sec. 3F, 4K, 5K were prepared by NJDOT Division of Design, Bureau of Geotechnical Engineering and Squad 5 of Region IV Surface Design. The contract was bid in October, 1987 and bids were received on November 25, 1987. The winning bid was awarded to Hess Brothers, Inc. of Parlin, New Jersey. Work on the project started in April, 1988. CPR work was substantially completed in September, 1989.

1. Location and Project Description

Route I-295, Section 3F, 4K, 5K

Federal Project No. NJ-IR-2(88)42

Beginning: Burlington-Mt. Holly Road (County Route 541)
MP 47.6 (Sta. 630+00)

End: US Route 130 MP 56.7 (Sta. 1112+00)

Length: 9.1 mi. (48,200 LF)

Burlington, Springfield, Mansfield, Florence, and Bordentown Townships, Burlington County.

2. Scope of Project

The CPR project on I-295 includes work on slab subsealing, full depth slab replacement, partial depth spall repair, joint cleaning and sealing, and longitudinal underdrain installation. Pavement grinding was added to the project at the resident engineer's discretion. Specific CPR contract quantities and bid prices are included in the following.

Slab Subsealing:
Holes Drilled For Subsealing....1,570 holes @ $ 50.00 = $ 78,500
Portland Cement for Subsealing....294 bags @ $ 165.00 = $ 48,510

Full Depth Slab Replacement:
Rem. Conc. Base & Surf. Courses..10,120 SY @ $ 25.00 = $ 252,500
Underlayer Preparation.....10,100 SY @ $ 2.50 = $ 25,250
Conc. Surf. Course Replacement,
9" th., Partial Length.....5,472 SY @ $ 51.00 = $ 279,072
Conc. Surf. Course Replacement,
9" th, Full Slab Length.....3,576 SY @ $ 69.00 = $ 246,744
Trans. Expansion Joints, Type A...1,905 LF @ $ 24.00 = $ 45,792

Seal Cracks and Joints in
Concrete Surface Course..... 257,896 LF @ $ 2.00 = $ 515,702

Longitudinal Underdrain..... 91,200 LF @ $ 14.00 =$1,276,800

3. Work Description

Slab Subsealing: Includes drilling holes through existing concrete slab and injecting a grout in order to fill voids in the subbase. Grout was injected under pressure. The slab was not displaced or lifted during subsealing. The grout mixture consisted of 1 part Portland Cement and 2.5 parts Flyash by volume with enough water to produce a flow of 10 to 16 seconds. This work is intended to fill subbase voids and ,in turn, reduce slab pumping and joint faulting.

Full Depth Slab Replacement: This work includes partial and full length slab replacement. The deteriorated 9" concrete pavement was saw cut into sections small enough to fit into the bed of a dump truck and removed by crane. The existing subbase was left in place and recompacted. A new concrete slab was poured in place and tied to the adjacent undamaged concrete with steel dowels and deformed bars to provide for positive load transfer. Type A transverse expansion joints were replaced as required. This work is intended to replace cracked, deteriorated concrete slabs with new concrete in order to restore ride quality and structural capacity to the pavement.

Partial Depth Spal Repair: This was not a contract item and was instead added on a spot basis to repair damaged surface concrete. Spalled concrete at the pavement surface was repaired by removing the cracked concrete to at least a 2" depth and replacing with a fast setting, concrete patch material. This work is intended to repair cracked concrete at the surface and arrest the development of more serious full depth slab cracking.

Cleaning and Sealing of Joints and Cracks: The joint or crack was prepared by removing the old sealant and debris and cleaning with compressed air. All joints or cracks wider than 1/4" were filled with hot poured rubber asphalt joint sealer to a 1" depth. The intent of this work is to waterproof the pavement joint and

prevent infiltration of surface water into the subbase. Debris was also cleaned out of the joints so that the concrete slabs can expand as required due to temperature changes.

Longitudinal Underdrain: Inclues installation of Type X longitudinal underdrain along the shoulder in order to facilitate sub surface drainage of the subbase. Work includes milling the distressed bituminous concrete shoulder, excavating a trench, placing filter fabric liner, perforated pipe and No. 57 stone, backfilling the trench and placing a new 6" bituminous concrete shoulder.

Diamond Grinding: This work consists of diamond grinding the concrete surface. The purpose is to restore ride quality and skid resistance to the existing pavement and reduce the level of transverse joint faulting.

4. Site Description

I-295, in the project area, is a main north-south artery which carries traffic between Trenton and the South Jersey area. The highway was constructed to interstate standards during 1972 through 1974 as a six-lane divided concrete highway with limited access. The surrounding area was mostly rural but is now experiencing rapid development as a bedroom suburb for Trenton and Philadelphia. Original construction contracts were administered as follows:

Sec. 3B & 4A	(1972)	MP 44.0 to 48.0
Sec. 4B	(1973)	MP 48.0 to 52.0
Sec. 4C & 5A	(1973)	MP 52.0 to 54.0
Sec. 5B	(1973)	MP 54.0 to 56.5
Sec. 5C	(1974)	MP 56.5 to 57.0

5. Design Traffic Data

By New Jersey standards, I-295, with design traffic of 29,000 vehicles per day, receives moderate traffic loading for an interstate highway. In comparison, some interstate highways in North Jersey receive in excess of 100,000 VPD.

AADT (1984)	= 29,280 VPD
AADT (2004)	= 52,880 VPD
DHV (2004)	= 5,500 Vehicles per hour
Heavy Trucks	= 15 %
Design Velocity	= 70 mph
Accumulated 18 kip Axle Loading (1972-1989)	= 9.3 million 18 K EAL (17 years)

6. Roadway Geometry

The roadway consists of three 12' lanes in each direction with 12' outside shoulders and 5' inside shoulders (Figure 4). the mainline is constructed of 9" thick reinforced concrete pavement with 3/4" expansion joints spaced at 78'-2". Bedding for the concrete pavement consists of a 12" thick bank run gravel subbase containing up to 12% fines. Shoulders are constructed of 2" bituminous concrete surface course, 7" gravel base course, and 12" gravel subbase.

The roadway horizontal alignment is generally straight with little superelevation. Vertical alinement is flat with maximum grades of 1%. A good portion of the highway was constructed on a clay embankment in order to cross an extensive stream and wetland area. The clay embankment is poorly drained and hinders proper drainage of groundwater from the pavement structure.

7. Climate

The weather conditions in the vicinity of the project is relatively mild typical of a humid, continental climate. Temperatures below 0 deg. and above 100 deg. F are rare. Summers are hot and humid and winters are cold and wet. The average July high temperature is 87 deg. and the average January low temperature is 22 deg. The yearly average ambient temperature is 52 deg. The di urnal temperature change between night and day averages 20 deg.

New Jersey receives a large amount of precipitation in any given year and ,in fact, ranks 10th among the 48 continental States in average annual precipitation. Only the 10 southeastern Atlantic and Gulf Coast States receive more rain than New Jersey. The total average annual precipitation is 44 inches. Precipitation is evenly distributed from month to month with maximum amounts occurring during the late summer months. Measurable rainfall occurs at least 100 days per year.

The average annual snowfall is 18" Single snow storms of 10" or more occur about once every 5 years. Maximum frost penetration ranges from 26" to 28". Approximately 20 freeze-thaw cycles occur in any given year.

8. Important References

The purpose of this study is to evaluate CPR design and construction techniques for use in rehabilitating New Jersey transverse expansion joint concrete pavement. Several important concepts are presented later in this report. To aid in CPR design and construction techniques, there are several available references that should be used by NJDOT staff on projects in the future:

American Association of State Highway and Transportation Officials (AASHTO), American Road and Transportation Builders (ARTBA), and Associated General Contractors of America (AGC), Guide Procedures for Concrete Pavement 4R Operations, Task Force 23, 1985.

United States Department of Transportation, Federal Highway Ad ministration, Field Inspection Guide for Restoration of Jointed Concrete Pavements, December, 1987.

United States Department of Transportation, Federal Highway Ad ministration, Pavement Rehabilitation Manual, September 1985, Supplemented Feb. 1989, FHWA-ED-88-025

D. PRECONSTRUCTION CONDITION OF I-295 ROADWAY

In order to establish a benchmark with which to gauge the success of the various CPR techniques along I-295, the pavement condition was evaluated prior to construction.

1. Visual Evaluation

The concrete pavement in the slow lane in both directions between MP 47.6 and 56.7 exhibited moderate to severe deterioration in the form of slab pumping (due to voids in the subbase), joint faulting, and full depth slab cracking. Areas requiring subsealing were determined by radar measurements (void detection) and visual observation of slab pumping during rain storms. Areas requiring slab replacement were determined by visual inspection of cracking. The extent of distress requiring subsealing or slab replacement is outlined in Table 2.

Table 2
Extent of Slab Distress on Rt. I-295

Section	Limits (MP)	Length (mi.)	% Length Subsealing NB	% Length Subsealing SB	% Length Slab Replace. NB	% Length Slab Replace. SB
I-295,4B,4C	48.0- 52.0	4.0	20%	32%	1.6%	0.6%
I-295,5A	52.0- 54.0	2.0	33%	54%	23.5%	16.0%
I-295,5B	54.0- 56.5	2.5	0.2%	18%	8.5%	7.5%

As summarized in Table 2, sections originally constructed along I-295, Sec. 4B,4C,5A,5B exhibit fair amounts of pavement distress requiring restoration. These sections were constructed during 1973 over an unfavorable, poorly drained clay and silt subgrade. The impermeable subgrade hinders drainage of the subbase and traps water directly below the pavement slabs. The trapped water, in turn, promotes slab pumping and erosion of the subbase resulting in joint faulting, loss of support, and full depth slab cracking. Clearly, the pavement distress originates from the use of poorly drained subgrade soils and impermeable, erodeable subbase materials.

2. Ride Quality

Measurements of before and after construction ride quality can be used to determine any increase in ride quality due to CPR techniques. Preconstruction Ride Quality Index (RQI) was deter mined using the ARAN vehicle (Photo 7). The ride quality of New Jersey pavements is determined through measurements of surface roughness, structural capacity (cracking, etc.) and traffic volume. RQI is measured on a scale of 0 to 5. In general, new concrete pavements in New Jersey exhibit a RQI of about 4.0. The terminal RQI, the point at which total reconstruction is required, is about 2.0. A summary of preconstruction RQI is presented in Table 3.

Table 3.
Preconstruction Ride Quality Index (RQI)

Section	Avge. RQI	
	NB	SB
48.0 - 52.0	3.41	3.35
52.0 - 54.0	3.31	3.37
54.0 - 56.5	3.42	3.40

As shown by Table 3, the preconstruction RQI ranged from 3.31 to 3.42. This is a fair ride quality, however the motorist can discern a moderate amount of roughness at this level. This roughness, which is largely due to joint faulting, causes a rocking motion to the vehicle which is barely noticeable to car drivers but is fairly objectionable to truck drivers.

3. Joint Faulting

Table 4 summarizes the preconstruction joint faulting measurements. Faults were measured in the slow lane of selected sections using a special tool.

Table 4.
Preconstruction Joint Faulting

Section (MP)	Joint Faulting NB	SB
48.0 - 52.0	0.21"	0.22"
52.0 - 54.0	0.12"	0.18"
54.0 - 56.5	--	0.10"

Note that the NJDOT Pavement Management Program has designated a 3/8" (0.375") or greater joint fault as a cause for concern. The preconstruction joint faulting shown in Table 4 ranges from 0.10" to 0.22", clearly less than the 0.375" cause for concern. The level of faulting is slightly noticeable to the motoring public yet is fairly objectionable to truck drivers.

4. Benkleman Beam Deflection Measurements

Slab deflection measurements can be used to evaluate the performance of subsealing and concrete slab replacemeny techniques. Preconstruction deflection measurements were taken at several test areas. Measurements were taken at the approach and leave end of the transverse expansion joint in order to measure joint efficiency (Photos 9 and 10). Preconstruction Benkleman beam deflection measurements are summarized in Table 5.

Table 5.
Preconstruction Deflection Measurements

I-295 (MP)	Average Preconstruction Deflection NB d1	NB d2	NB Jt. Eff	SB d1	SB d2	SB Jt. Eff.
48.0 - 52.0	9.5	8.0	84%	5.5	4.5	81%
52.0 - 54.0	4.5	4.0	89%	10.0	7.5	75%
54.0 - 56.5	---	---	--	9.0	7.0	77%

Note

d1= deflection at approach edge of trans. expansion joint (x.001)

d2= deflection at leave edge of expansion joint (x.001")

Jt. Eff. = Joint Efficiency = {2 (d2)/d1 + d2)} 100

70 -100% : Good to Excellent

50 - 70% : Fair

0 - 50% : Poor

All deflections measured in slow lane, outside wheelpath @ 3' from edge of shoulder.

Table 5 shows that all deflections average less than 0.10". By comparison, deflections in excess of 0.20" indicate that structural capacity has deteriorated to an level requiring major reconstruction. The deflections along I-295 are reasonably low.

The joint efficiencies average between 70 to 90%, which is good to excellent after 16 years of service. These favorable joint efficiency measurements indicate that the New Jersey Type A transverse expansion joint devices (with stainless steel encased dowels) are still performing as designed and are adequately tranferring loads across the joint.

5. Longitudinal Underdrain Survey

Approximately 91200 LF of longitudinal underdrain were in stalled along the shoulder area in order to provide for subsurface drainage of the subbase. Approximately 85200 LF were in stalled with the standard NJDOT Type X stone and perforated pipe underdrain. The remaining 6000 LF were composed of 3 experimental geocomposite edge drain products including Hydraway, AdvanEdge (ADS) and Akwadrain. A complete summary of the geocomposite edge drain evaluation is included in a separate, companion report.

E. CPR CONSTRUCTION

CPR work along I-295, Sec. 3F, 4K, 5K commenced in March, 1988 and, except for the winter break, continued until September, 1989. The contractor was Hess Brothers, Inc. of Parlin, NJ. The following CPR techniques were constructed during the 1 1/2 year project:

1. Slab Subsealing
2. Full Depth Slab Replacement
3. Partial Depth Spall Repair
4. Cleaning and Sealing of Joints
5. Longitudinal Underdrain
6. Diamond Grinding

Most of the pavement distress such as pumping, cracking and spalling was concentrated in the right hand lane of the highway. This is due to the pounding of heavy trucks, 85% of which travel in the right lane or what is commonly known as the "truck" lane. Since the truck lane is most heavily traveled, this lane receives most of the damage and in turn must be slated for CPR.

CPR work along busy interstate highways requires extensive (and expensive) traffic control. On this project, contract plans were developed for scenarios where different lanes were closed for repair. The most important and frequent CPR traffic control plan occurred when the right hand lane and outside shoulder were closed for repairs. This setup left the middle and fast lane open for the passage of traffic .

CPR operations such as full depth slab replacement requiring lane closures for more than 4 hours were protected with precast concrete "Jersey" barriers. Installation of the heavy "Jersey" barriers is a tedious and expensive operation requiring a crane, 2 or more flatbed trucks, and a crew of at least 10 laborers.

CPR operations such as subsealing, joint sealing, underdrain installation and grinding which are dynamic and require temporary lane closures can be protected with a system of drums and barricades.

Protection of temporary lane closures with barricades or barrels is much less expensive than use of the heavy "Jersey" barriers. CPR operations should be designed so that lanes can be safely closed for less than 4 hours thereby allowing the use of less expensive drums and barricades.

Traffic control is expensive. Bid prices for the I-295, 3F,4K,5K project:

Traffic Control: $ 1,100,000
CPR work : $ 5,500,000

Traffic control cost = 20% of the CPR work!

Another important consideration is the sequence of CPR operations. Subsealing and full depth slab replacement should be done prior to longitudinal underdrain installation and shoulder rehabilitation. Otherwise, if subsealing was conducted prior to the underdrain work, grout could seep into the stone drain. Also, portions of the shoulder must be removed during slab replacement work. Therefore, it is more prudent to remove and replace slabs prior to any shoulder rehabilitation.

1. SUBSEALING

Subsealing commenced on July 26, 1988 and continued until early October. The operation started in the northbound lanes at the southerly end of the project near the rest area and continued north toward Bordentown. After the northbound lanes were subbsealed, the operation moved to the southbound lanes and continued south to finish the work.

Only the right hand (truck) lanes were subsealed since these lanes were the only ones suffering from slab pumping and voids in the subbase. Figure presents a detail of the susealing hole net work.

Grout Mix Design

Mortar Cube Spec. 7 day Strength: 800 psi.

Flow: 10 -16 sec.

1 part Cement

2.5 parts Flyash

Water: Enough to produce flow of 10 - 16 sec.

Materials

Portland Cement: Coplay Type II (94# bags)

Flyash: Montour Type F (75# bags)

Subcontractor: Prepakt Concrete Co.
Turnersville, NJ

Labor

4 Laborers
1 Foreman
1 Flagman

Equipment

1 - Ford F350 Flatbed Truck (for transporting bags of cement)

1 - Ingersall Rand Diesal Pump mounted on trailer

1 - Ford F700 truck mounted with 1000 gal. water tank and Briggs and Stratton 3 HP pump.

1 - Colloidal Mixer mounted on trailer with hopper for mixing a 40 gal. batch of grout (cement, flyash, and water)

Field Mix Design (for 20 gal. of Grout)

1 - 94# bag of cement
2.5 - 75# bags of flyash
19.3 gal Water, enough to produce flow of 10 sec.

Note for 40 gal. batch: mix design is 2 bags cement, 5 bags flyash, and 38.6 gal water.

Subsealing Procedure

1. Drill 1 1/4" or 1 1/2" dia. holes at proper spacing.

2. BLow out drill holes with compressed air to ensure clean pas sage for grout.

3. Pump grout into first hole at about 50 to 100 psi. Continue pumping grout until one of the following occurs:
    a. Grout is observed flowing from the other holes or cracks.

    or

    b. The slab raises more than 0.125" (1/8").

    or

    c. The pump pressure at the outlet rises above 125 psi.

4. Pump grout into the second hole and so on until all four holes have been filled with grout.

5. Plug the holes with a non-shrink grout

6. Continue to next set of holes.

Flow cone tests (ASTM C939) were conducted twice per shift. Generally, flows were about 10 or 11 sec. or at the more liquid end of the specification. It is easier to start with a "thin" mix design and if needed, more cement and flyash can be added to thicken the grout.

Mortar cubes were prepared for compressive strength testing once each day for the first 3 days of subsealing and thereafter once per week for the balance of the job. The specified 7 day grout strength was 800 psi. However, there were problems obtaining the 800 psi. strength at 7 days. Samples of cement and flyash were checked and found to be sufficiently within NJDOT specifications therefore substandard materials were not used. Since the intent of subsealing is to merely replace voids in an unstabilized gravel subbase, the specification can be relaxed from 800 psi. A specificaton 7 day strength of about 400 psi should be sufficient for subsealing. Strengths in excess of 400 psi. at 7 days and 600 psi. at 14 days were commonly obtained during the project. The following summarizes the grout compressive strength testing during the first week of subsealing.

Once subsealing was started, the operation progressed very smoothly. A typical day's subsealing is presented below:

9:30 AM Close right hand lane after morning rush hour.

Sta. 750+18 NB

10:20 AM Drill 4 hole pattern and blow with pumped air.
Pumped air is flowing cleanly from 4 holes and shoulder
Begin mixing of grout.

10:36 AM Contents of grout mixed to fill 40 gal. hopper.
Flow cone test. Flow = 10.1 sec. (OK)

10:40 AM Start pumping grout into 1st hole @ 100 psi.

10:48 AM Pump pressure reaches 125 psi, stop pumping.

10:50 AM Start pumping grout into 2nd hole

10:51 AM Stop pumping, grout observed flowing from 3rd hole

10:54 AM Start pumping grout into 4th hole.
10:55 AM Stop pumping, grout observed flowing from adjacent longitudinal joint.
10:57 AM Start pumping grout into 3rd hole.
10:58 AM Stop pumping, observed grout flowing from shoulder joint.
11:00 AM Patch 4 holes with non-shrink grout, move on to next set of holes. Total grout quantity for 4 holes = 20 gal

Break for Lunch

Sta. 769+00 NB

12:30 PM Start pumping grout into hole #1
12:32 Stop pumping, grout observed flowing from adjacent hole #2.

12:53 Start pumping grout into hole #2 at 50 psi.
12:56 Stop pumping, grout observed flowing from hole #3.

12:58 Start pumping grout into hole #3.
12:59 Stop pumping,grout observed flowing from shoulderjoint.

1:03 Start pumping grout into hole #4
1:05 Stop pumping, grout observed flowing from joint.

1:07 Make six - 2" x 2" grout mortar cubes for compressive strength testing.

1:10 Patch 4 holes with non-shrink grout. Move on to next set of holes. Used 10 gal. of grout for 4 holes.

Sta. 770+00 NB

1:18 PM 2nd flow test of day. Flow = 10.8 sec. (OK)

1:20 Start pumping grout into hole #1.
1:21 Stop pumping, grout observed flowing from hole #2.

1:24 Start pumping grout into hole #3
1:26 Stop pumping, slab raised more than 0.125".

1:27 Start pumping grout into hole #4
1:28 Stop pumping, pump pressure in excess of 125 psi.

1:29 Start pumping grout into hole #2
1:31 Stop pumping, pump pressure in excess of 125 psi.

1:35 Patch 4 holes with non-shrink grout. Move to next set of holes. Used 10 gal. of grout.

Sta. 771+00

1:42 PM Start pumping grout into hole #1.
1:43 Stop pumping, grout observed flowing from hole #2.

2:02 Start pumping grout into hole #2.
2:03 Stop pumping, grout observed flowing from hole #3

2:04 Start pumping grout into hole #4.
2:04 Stop pumping, grout observed flowing from long. joint.

2:05 Start pumping grout into hole #2. Pumping at 60 psi.
2:06 Stop pumping, observed grout flowing from shoulder jt. Used 10 gal. of grout for 4 holes.

Sta. 771+50

2:18 PM Start pumping grout into hole #1.
2:20 Stop puming, grout observed flowing from hole #2.

2:22 Start pumping grout into hole #2. Grout is forcing clear water from beneath slab.
2:24 Stop pumping, grout and clear water observed flowing from shoulder joint.

2:28 Start pumping grout into hole #3 at 40 psi.
2:30 Stop pumping, grout observed flowing from transverse crack at midpoint of slab.

2:33 Start pumping grout into hole #4 at 70 psi.
Free water observed flowing from shoulder joint.
2:38 Stop pumping, grout observed flowing from long. joint
Patch 4 holes with non-shrink grout.
15 gal of grout used.

Sta. 778+00

2:45 PM Flow Test. Flow = 11.3 sec. (OK)

2:48 Start pumping grout into hole #1. Free water observed flowing from hole #2.
2:50 Stop pumping, grout observed flowing from hole # 2.

2:52 Start pumping grout into hole #2
2:58 Stop grouting, free water observed flowing from shoulder followed by grout.
40 gal. of grout pumped into 2 holes.

Stop for Day

The subsealing was similarily continued for the remaining 3 months of operations. The following observations can be made about the subsealing along I-295.

1. The subsealing subcontractor, Prepakt Concrete Co. of Turnersville, performed very satisfactorly. This job was the first instance of subsealing on an NJDOT CPR project. Therefore, the Department had to rely on the expertise and guidance of the contractor. Overall mix deign, grout mixing and grout pumping operation was first rate.

Subsealing should not be confused with mudjacking or slabjacking, both of which had been previously performed by NJDOT Maintenance forces. Subsealing is intended to fill subsurface voids without raising the slab. Whereas mudjacking is intended to raise and restore the slab to the original elevation.

2. Approximately 7 to 8 sets of holes could be subsealed in the 6 hour workday from 9:00 AM to 3:00 PM. The workday was restricted to 6 hours due to the need to keep all 3 lanes open during the morning and evening rush hours. An average of 10 to 20 gal. of grout was pumped into each set of 4 holes. This is equal to a grout volume of 1.5 to 3.0 cu. ft. or enough grout to fill a void ranging from 1/4" to 1/2" thick over a 6' x 12' slab area.

3. The necessary grout quantities were underestimated by about 30% over the course of the project.

Estimated Grout Quantities

Portland Cement for Subsealing 294 bags @ $165.00/bag = $48,500
Holes drilled for subsealing 1570 holes @ $ 50.0/hole = $ 78,500

1570 holes x 1 set/4 holes = 392 sets

392 sets x 20 gal. grout/set = 7840 gal. grout

7840 gal. grout x 1 bag Cement/20 gal. = 392 bags of Cement used

Estimated Cement Quantity Used = 294 bags

392/294 = 130% , Therefore voids for grouting were underestimated by 30%.

Apparently there were larger voids under the slabs than originally estimated.

6. Subsealing is very inexpensive. The total cost for subsealing each set of 4 holes is only $ 365.00. Since the subsealing is constantly moving, a temporary traffic control plan using barrels only costs $ 80.00 for each setup.

Assume 20 gal. of grout used for each set of 4 holes. 1 bag of cement per 20 gal. of grout.

```
1 bag cement       = 165.00
4 holes @ $ 50.00 = 200.00
--------------------------
 Subsealing Cost  =$365.00
```

Traffic control: Barrels $ 2.00 spaced at 50' for 2000' = $ 80.00.

7. Large quantities of free water were forced from underneath the slabs during the grouting operations. This water was trapped be tween the subbase and the pavement and could not drain due to the impermeable subgrade conditions. This subbase water causes damage in the form of pumping and loss of support which in turn costs settlement and slab cracking. The subsealing removes this trapped water and resulting voids are filled with grout, thus serving to halt water related pavement damage.

8. The specification 7 day strength of 800 psi. was never obtained during mortar cube testing. The project specifications required a 7 day strength of 800 psi using a mix design of 1 part cement to 3 parts flyash. The contractor could not obtain the desired strength at this mix design. Actual strengths obtained were 400 psi. at 7 days and 600 psi. at 14 days using a 1 part cement to 2.5 part flyash mix design.

Since the contractors could not obtain the desired 800 psi at the 1:3 mix design, it is recommended that future specifications require a only a minimum grout design strength and flow. The contractor would be responsible for determining a mix design provided it meets the minimum strength and flow. A recommended design strength should be 400 psi at 7 days with a flow between 10 and 16 seconds.

The lower design strength of 400 psi. can be safely used be cause the grout under the slabs is very stable even in liquid form. The grout is forced under the slabs at high pressure and is immediately confined by plugging the holes. Since the grout is an incompressible liquid, the grouted slabs can carry traffic immediately after subsealing. After 2 or 3 hours, the grout sets and starts to harden, gradually gaining strength until approximately 1000 psi are reached after 28 days. On this project, the traffic was kept off the grouted lane for 2 or 3 days. How ever, on future projects, grouted lanes can be safely reopened immediately after subsealing due to the high stability of the confined liquid grout and ensueing gradual long term strength development of the hardened grout.

9. Prior to the subsealing operation, there were concerns that the pressure grouting may not be compatible for use adjacent to the New Jersey Type A expansion joint. Since most of the subsealing was specified adjacent to joint areas, there were concerns that the grout might be forced up into the 3/4" expansion joint opening eventually restricting the free movement of the joint. Close inspection indicated that, in no case, did the grout flow up through the expansion joint. The joint is filled with a 3/4" fiber board which successfuly prevents grout and other foreign material from infiltrating and fouling the joint. Subsealing can be successfully conducted along New Jersey Type A expansion joiny concrete pavements as long as the bottom portion of the fiber board remains somewhat intact.

2. FULL DEPTH SLAB REPLACEMENT

The purpose of full depth slab replacement is to remove cracked and damaged concrete and replace with a new poured in-place full depth concrete slab. Slab replacement is the most tedious of the various CPR techniques and requires expensive, heavy equipment during sawcutting, slab lift out, and in-place concrete pouring operations.

Since the new concrete slabs are left to cure for three days prior to reopening lanes to traffic, expensive traffic control using precast concrete "Jersey" barriers was required. In many cases, the cost of traffic control exceeded the construction cost of slab replacement. Slabs with transverse cracks, severe spalling, settlement cracks and other miscellaneous cracks were marked for replacement.

The slabs were sawcut by one of two methods: (1) cutting with a diamond blade saw or (2) cutting with a vermeer saw. The diamond blade saw leaves a clean cut and is preferred over the use of the vermeer saw which leaves roughly spalled and chipped edges. On slab replacement in the slow lanes, the majority of the cutting was done using a vermeer saw. Later in the project, fast lane slab replacement was done using the diamond bladed saw. A comparison of the two methods indicates that the diamond bladed saw leaves clean edges and is clearly the preferred method of saw cutting for the full depth slab replacement.

Procedure

1. Mark out limits of slab replacement. Minimum slab length is 6'. All damaged concrete was marked for replacement. Limits of replacement should extend at least 1' into sound, undamaged concrete.

2. Make transverse sawcuts at 6' intervals using the vermeer saw or diamond blade saw. The outer saw cuts located adjacent to sound concrete were made with a diamond blade saw in order to leave a clean cut.

3. At each 6' x 12' section, holes were drilled in preparation for insertion of the lift out pins. The pins were fashioned from old automobile axles. This is an ingenious use of the old yet very high strength axles. The axle pins possessed more than sufficient strength to support the lifting of each 4 ton slab.

4. Place lift out pins in slab holes. Attach crane hooks to pins. Lift slab with crane. Place 6' x 12' slabs into dump truck. The 6' wide slabs were cut just wide enough to fit into the back of the dump trucks. Slabs were trucked to Mount Holly Concrete and recycled for use as aggregate base course.

5. Prepare missing slab area for new concrete pour. Drill holes and install load transfer devices. Holes were drilled into longitudinal joint edges for placement of 18" long, #6 deformed bars. 2 bars were installed per 6' length of the longitudinal joint. Place epoxy into hole, insert deformed bars into epoxied holes and let cure.

6. Drill holes for insertion of dowels at the transverse saw cuts. Insert 18" long, 1 1/8" dia. dowels into epoxied holes. 8 dowels per 12' lane width were installed in order to provide for proper load transfer between the new concrete slab and the existing sound concrete.

7. If location of slab replacement is at transverse joint, in stall new Type A expansion joint dowel device.

8. Tack sides of existing concrete and load transfer bars/dowels with asphalt cement tack coat.

9. Compact existing subbase. All areas should be compacted with a vibratory plate compactor.

10. Prepare for concrete pour. Install wooden form along shoulder edge.

11. Wet down subbase. Pour first layer of concrete about 6" deep. Vibrate the concrete especially around slab edges, dowels and joint devices. Place wire reinforcement over vibrated first lift of concrete.

12. Pour second and final layer of concrete. Vibrate and conduct preliminary finishing with trowels.

13. Conduct final finishing with 12' long vibratory screed. If the patch is less than 12' wide, position the screed parallel to traffic and finish transversely. If the patch is more than 12' wide, position the screed perpendicular to traffic and finish longitudinally.

14. Conduct minimal hand finishing after vibratory screeding. Let concrete set. Texture transversely with a tine rake. Spray curing compound. Let cure for 3 days prior to reopening lane to traffic.

Concrete Materials

Producer: Mt. Holly Concrete Co.

Cement: Hercules Type II

Fine Aggregate: Clayton Sand, Woodmansie, NJ

Coarse Aggregate: No. 57 stone, Traprock Industries, Moores Station, NJ

Admixture: Euco Air Mix, R-75 Retarder, Euclid Chemical Co.

Mix Design (per cu. yd.)

Class B, air entrained concrete.

Design Strength = 3000 psi. at 3 days.

Cement, Type II: 705 lb. per c.y.

Fine Agg.: 1150 lb.

Coarse Agg.: 1930 lb.

Retarder R-75: 35.5 oz.

Design Slump: 2" +/- 1"

Entrained Air: 6 +/- 1.5%

Mix was designed for accelerated strength development so that lanes could be reopened to traffic. Therefore a high cement con tent of 705 lb. per c.y was used.

Actual 7 day strength Results: 3870, 3490, 4705 psi.

Inspection of the full depth slab replacement during and just after construction indicates the following.

1. Slab replacement can be staged such that sawing can progress ahead of the concrete pouring operations. Lanes can be sawed with the narrow diamond blade saw and the 2" wide vermeer saw and reopened to traffic prior to slab lift out work. Traffic can pass over the narrow saw cuts without disruption.

2. The specification requires compaction of the subbase prior to the new concrete pour. However, the method of compaction was not specifically identified. In many cases the contractor superficially compacted the subbase with the wheel of a front end loader.

On future projects, the specification should require that the existing subbase, if left in place, should be compacted with a vibratory plate compactor.

3. On this project, the existing subbase was left in place. How ever, the impermeable subbase material was, in many cases, the source of slab distress due to pumping and erosion. By leaving the existing subbase in place, the unfavorable foundation problem was not resolved. This uncorrected foundation problem provides the potential for cracking, pumping, and settlement of the new concrete slabs. Therefore it is recommended that on future slab replacement projects, the existing subbase should be removed to a 4" depth and replaced with free draining, non-erodeable Non-stabilized Open Graded Base (NSOG) material. The NSOG will resolve the poor drainage problem and ensure that the new slabs will be supported by a non-pumping, high quality foundation material.

4. The Type A joints removed during slab replacement were examined and found to be in good condition after 16 years of service. The joints and stainless steel dowels were not corroded or other wise damaged by exposure to road salt. This indicates that the distress along I-295 was not due to failure of the joint devices but rather due to the more obvious problem of pumping and voids in the subbase.

5. The quality of slab replacement was much better in the SB lanes than the NB lanes. All slabs in the SB lanes were replaced during the latter stages of the project. This indicates that, like all other construction operations, the contractor experienced a learning curve during the slab replacement work. Slabs replaced in the SB lanes during the second half of the project had better ride quality and lower rate of construction related chipping and cracking problems than the slabs in the NB lanes which were constructed during the first few months of the project.

6. Transverse cracks were observed at several locations where 3 or more continuous full length slabs were poured together. Construction records indicate the subject slabs were poured during temperatures that exceeded 90 deg. The high temperatures caused expansion during initial set and when the hydration water evaporated, the slabs contracted, leaving transverse contraction cracks. In accordance with American Concrete Institute (ACI) practice, concrete pours should not be conducted when temperatures may be expected to exceed 90 deg.

7. At several locations the surface roughness and ride quality of the new slabs was very unsatifactory when finished with the screed longitudinally. Longitudinal screeding (advancing the screed in the direction of traffic) leaves a small "hump" at the leave end of the slab. The longitudinal drags increase roughness by pulling the wet concrete to one end of the slab thus causing a small bump that is barely noticeable to the naked yet is very noticeable when traveling over in a vehicle. It is recommended that all slab replacement be finished with a vibratory screed designed to travel transversely.

Another alternative to ensure adequate rideability is to require diamond grinding of all new concrete patches. Diamond grinding produces a surface with low roughness that is equal to or superior than new concrete pavement construction.

8. All sawcuts should be conducted with a diamond bladed saw. The diamond saw is faster, produces a cleaner cut, and is less cumbersome than a vermeer saw which produces rough cuts, large quantites of dust, and is rented from specialty subcontractors at great expense. The diamond blade saw is portable and can be purchased at low cost. Clearly the diamond saw is preferred over the vermeer saw for slab lift out work.

9. The holes for load transfer bars and dowels were drilled by hand. This is not the accepted practice in the industry since hand drilling with heavy equipment produces loose, crooked holes. In the future the specification should require that all holes should be drilled with a stationary, mechanized drill gantry.

10. After curing, the wooden side form should be kept in place to prevent edge breakoff. At several new slabs, the forms were removed and edges and corners were broken off due to the passage of construction vehicles. The wooden form should be kept in place until the adjacent shoulder is repaired so that premature edge breakoff does not occur at the protruding lip.

11. After 3 days cure, strength development of the concrete was adequate for the reopening of traffic provided that the shoulder was repaired adjacent to the slab. Compressive strengths in excess of 3000 psi were obtained at 3 days cure

12. It is recommended that future projects should seriously consider the addition of 2% Calcium Chloride accelerator to increase the rate of strength development of the new pavenent slabs.

The disadvantage of full depth slab replacement as used on the I-295 project is that the repaired lanes had to remain closed to traffic for 3 days before the concrete (with 705# Type II cement per CY, without accelerator) cured and gained sufficient strength. Since the lanes had to be closed over night, expensive "Jersey" barrier traffic control was required. An alternative is to add 2% Calcium Chloride as an accelerator to the wet concrete mix just before pouring. The addition of CaCl2 accelerates strength gain and permits traffic to be reopened 4 hours after pouring concrete.

The advantage of using concrete with an accelerator is the lanes are closed for about 6 hours (2 hours for slab cutting and lift out, 4 hours for concrete cure) as opposed to 3 days with the regular concrete mix. Therefore, less expensive temporary barrels can be used for traffic control with significant cost savings.

There are concerns that the addition of CaCl2 salt may promote corrosion of reinforcing steel and dowels. However, studies have shown that slab repairs using concrete with 2% CaCl2 accelerator have outlasted the existing undamaged pavement. The existing unrepaired pavement eventually fails far sooner than the patches with added CaCl2. Therefore, the potential corrosive effects of CaCl2 would not be a factor in the performance life of new slabs.

3. PARTIAL DEPTH SPALL REPAIR

Minor cracking and spalling of the concrete surface was repaired by removing the cracked concrete to a depth of about 2" to 3" and replacing with a partial depth, fast setting patch. The potential advantage of partial depth spall repair is that the fast setting concrete patch materials allow reopening of lanes within 3 to 4 hours. The spall repair procedure is fairly simple and can be summarized as follows.

Spall Repair Procedure

1. Mark out area of spall repair. All damaged concrete should be removed. Unsound concrete may be identified by dragging a chain across the suspect area. Unsound concrete will produce a dull ring whereas sound concrete will produce a clean sounding ring.

2. Cut edges of repair in a rectangular pattern using a diamond saw to make a clean edge.

3. Remove all damaged material down to sound concrete from within the saw cut edges.

4. Clean the roughened concrete surface of the repair with compressed air.

5. Repair the area with a fast setting patch material such as Set 45 or any other of the proprietary materials on the market. Finish the spall repair flush with the adjacent pavement.

6. Let the patch cure for 3 to 4 hours and reopen the lane to traffic.

Inspection of the partial depth spall repairs immediately after construction indicates that this method of concrete repair is highly unsatisfactory. The repairs areas cracked immediately after reopening to traffic. A more successful technique is to repair all damaged concrete full depth. The spall repair failure mechanism is discussed later in this report.

4. JOINT SEALING AND CLEANING

Existing transverse and longitudinal joints, and cracks mea suring 1/4" or wider were cleaned and sealed in order to remove incompressibles and waterproof the pavement. Although joint seal ing is a routine procedure, extensive traffic staging is required and actual cleaning and sealing work is surprisingly expensive. On this project, approximately 260,000 LF of joints and cracks were resealed at a cost of $ 520,000! The cost of joint sealing was nearly as much as the cost of the more tedious full depth slab replacement work!

Procedure

1. Joints to be sealed were cleaned to a depth of 1" by a combination of routing and sawing old joint sealer and debris from the joint. Following removal of dirt and loose material, the joint faces and cracks were cleaned by means of a mechanical wire brush and compressed air.

2. The hot poured rubber asphalt joint sealer was guided into the joint or crack using a sealer wand. The hot pured rubber asphalt joint sealant conforms to ASTM D-1190. Excess sealant was removed from the adjacent concrete surface using a squeegee.

3. The sealant was poured flush with the adjacent concrete surface. Traffic was not permitted over the poured joints and cracks until the sealant had hardened to resist pickup by tires.

5. LONGITUDINAL UNDERDRAIN

Approximately 91,200 LF (17.3 mi.) of longitudinal underdrain was installed along the concrete pavement/shoulder joint in order to provide for subsurface drainage of the subbase. The standard NJDOT Type X stone and perforated pipe underdrain was installed along 85200 LF of the project. Three experimental Geocomposite Longitudinal Edge Drain products including Hydraway, AdvaEdge (ADS), and Akwadrain was installed along the remaining 6000 LF of the project. The experimental geocomposite drains were installed along the NB shoulder from Sta. 644+00 to 704+00 between Route 541 and the NB Rest Area. The installation and initial evaluation of the geocomposite drains is summarized in a separate report.

Type X Underdrain Installation Procedure

1. Mill and remove existing 2" bituminous concrete shoulder.

2. Excavate the 24" wide by 27" deep trench in the shoulder directly adjacent to the concrete pavement. Invert of trench should be parellel to pavement surface. A Vermeer trencher was used.

3. Line the trench with non-woven filter fabric.

4. Place 6" lift of pervious, AASHTO No.57 (3/4") stone on bottom of trench.

5. Place 6" dia. perforated, corrugated polyethylene plastic pipe on the 6" stone bedding. Perforations should be face down. After the first 5000 LF of placement, the procedure was later modified to delete the stone bedding and place the pipe directly on the trench bottom.

6. Backfill the trench with No. 57 stone to the desired elevation at 6" below the pavement surface.

7. Enclose the top of trench with the filter fabric flap.

8. Construct 6" dia. nonperforated outlet pipes at approximate 500'intervals. Pipes were tied into existing catch basins in cut sections and daylighted to sideslope ditches at fill sections

9. Resurface shoulder full width with 6" of bituminous concrete. Although not technically part of underdrain installation, the new bituminous concrete surface serves to close the concrete pave ment/shoulder joint and prevent inflow of water through the joint into the subbase.

The following observations can be made about the longitudinal underdrain installation.

1. Type X underdrain installation proceeded very smoothly. The trenching and pipe laying procedure was highly mechanized. In some cases, close to a mile per day of pipe could be installed.

2. The original Type X drain detail required a 6" stone layer at the bottom of the trench to provide bedding for the pipe. How ever, water tends to flow underneath the pipe through the pourous stone when bedding is provided. Therefore after 5000 LF of installation, the 6" stone bedding was simply deleted and the pipe was merely placed on the bottom of the trench. The revised detail not only aided in better collection of water the perforated pipe but also expedited installation by allowing the contractor to backfill the trench in one lift instead of 2 separate lifts.

3. The outlet pipe detail originally specified that the trench should be backfilled with native soil. However, the NJDOT inspector found that drainage of the subbase around the outlet pipes could be expedited by backfilling the trench with the No. 57 stone. Therefore, the outlet detail was changed to allow backfilling of the trench with pervious stone .

4. The installation of Type X Underdrain was a very high cost item. At a cost of $ 14.00 per LF, the installation of 85,200 LF of Underdrain cost about $ 1.2 million! This was the most expensive of the CPR techniques. As described in a separate report, the geocomposite edge drains were installed for $ 6.00 per LF, at a savings of $ 8.00 per LF.

5. The locations of proposed outlet pipes should be marked on contract plans prior to construction. At several areas, the out let pies had to be constructed at intervals exceeding 500 feet due to absence of a suitable outfall slope or available catch basin.

6. At several areas, outlet pipes were not constructed. This is due to fact that outlet locations were not marked on the plans and locations had to be marked in the field. Construction inspection and asbuilt inspection of completed outlet pipes is much simplified by marking locations on construction plans prior to installation

7. The plans mistakenly specified a minimum pipe slope of .005%. This slope is virtually flat at about 0.005 feet vertical for every 100 feet horizontal. Although the mistake was due to a typrographical error, some pipes were improperly constructed at the nearly flat slope before the problem could be rectified and are not draining properly. All future outlet pipe details should specify a minimum slope of 1.0% to ensure proper drainage.

6. DIAMOND GRINDING

Although not originally specified for the I-295, Sec. 3F,4K,5K project, diamond grinding is a very useful CPR technique used to level faults, reduce roughness, and restore skid resistance to the concrete surface. Diamond grinding was eventually used on the I-295, 3K,4K,5K project to improve the substandard surface roughness of several full depth slab replacement areas. The first widespread use of diamond grinding on an NJDOT project was conducted in 1987 along I-295, Sec. 1X in Gloucester County.

On the I-295 Sec.1X project, the work consisted of using diamond blades to texture the concrete pavement after all patching and repairs were complete. Diamond grinding was conducted prior to joint sealing and shoulder resurfacing work. The grinding leaves the existing concrete pavement with a uniform longitudinal corduroy type texture consisting of grooves between 0.09" (3/32") and 0.130" (1/8") wide and approximately 1/16" deep with spaces between grooves measuring 0.06" (1/16") and 0.125" (1/8") wide. This work restores smoothness to faulted and warped pavement. The pavement is ground in 38" wide passes going with traffic. Excellent texture and skid resistance is obtained.

On the I-295 1X project, the grinding was so successful that the existing grinded 16 year old pavement was smoother and has better rideability than recently constructed pavement using standard finishing techniques.

Due to the success of diamond grinding on the I-295 Sec.1x project, it is recommended that grinding be specified for all CPR projects in the future to restore smoothness, correct falts, and restore skid resistance to the concrete pavement surface.

F. ALKALI-SILICA REACTION

During the initial field stake out for the I-295, 3F,4K,5K project, the Resident Engineer discovered that the fast lanes in both directions between MP 48 and 54 exhibited very fine "map" or pattern cracking of the concrete surface. An extensive laboratory investigation concluded that the fast lane and to a lesser ex tent, the slow and middle lanes were suffering from alkali-silica reaction. During this project approximately 200 additional joints were replaced with double wide fiber board to accommodate the ``growing'' pavement.

G. POST-CONSTRUCTION EVALUATION

The performance of the various CPR techniques were evaluated immediately after construction. The post-construction evaluation can be used to gauge the success of the individual techniques and estimate expected service life.

1. SLAB SUBSEALING

As noted earlier in the report, the slabs were subsealed in a very satisfactory and workmanlike manner. Approximately 10 to 20 gallons of cement/flyash grout was pumped into each set of 4 holes at selected joint and mid-slab areas in an effort to fill voids in the subbase and in turn halt pavement slab pumping.

The initial inspection conducted over the course of 1 year under traffic indicates that the combination of subsealing together with longitudinal underdrain installation have indeed halted slab pumping along the 8.6 mile project. Inspections during rain storms indicate no evidence of shoulder stains, shoulder deterioration, subbase water ejection, or any other evidence that pumping has reoccurred except at one small 500' long section located along the NB shoulder near the Florence-Columbus Road interchange.

A comparison of preconstruction and postconstruction Benkleman beam measurements indicate that the additional subbase support provided by subsealing has reduced pavement deflections between 20% to 23% (Table 6).

Table 6
Comparison of Pre- and Postconstruction Deflection Measurements along Subsealed areas, I-295.

Deflections @ Sta. 785+00 to 803+00 and 823+00 to 835+00, NB

	Preconstruction	Postconstruction	% Reduction
d1	5.8 mil	4.7 mil	23%
d2	5.0 mil	4.1 mil	21%

Joint faulting after subsealing has remained the same as prior to subsealing because the pavement surface was not diamond grinded. Although voids are filled, subsealing does not correct surface roughness deficiencies. A combination of subsealing and diamond grinding can reduce pumping and grind down faults to an acceptable level.

Cores of the subsealed areas indicate that the thickness of grout ranges from 1/4 to 3/4". This means that subbase voids prior to subsealing were of similar dimensions.

The initial evaluation after 1 year of traffic indicates that susealing has been successful. When used in combination with longitudinal underdrains, subsealing has halted pumping and reduced deflections, thus increasing the structural capacity of the 16 year old concrete pavement along I-295.

An initial estimate based on this project and experiences from other States indicates that subsealing should halt pavement pumping for at least 5 years.

2. FULL DEPTH SLAB REPLACEMENT

An evaluation of the full depth slab replacement areas conducted after 1 year under traffic indicates marginally satifactory performance. The old deteriorated concrete has been removed and replaced with new full depth pavement slabs and structural capacity has been greatly improved. However, a good portion of the slabs have suffered from minor corner, edge, or transverse cracking.

It should be noted that the NB lanes were replaced during the 1st half of the project and the SB lanes were replaced during the second half of the job.

A condition survey indicates that in the NB lanes, 35 of the 65 new slabs (54%) have minor corner, edge or transverse cracks. In the SB lanes, 16 of 47 new slabs (34%) have minor cracks. Al though cracking in any form is undesirable, slabs replaced during the second half of the project in the SB lanes experience a lower incidence of minor cracking than those in the NB lanes. This indicates that the quality of work improved as the project progressed.

It should be noted that the corner, edge, and transverse cracks are barely noticeable at traffic speed and in no way compromise the quality or structural capacity of the new slabs at this time. While it is better to have no cracking at all, the minor cracking found during the condition survey could be a problem that cannot be avoided due to the pressure of saw cutting and pouring slabs under traffic and the difficulty of tieing new concrete to old. Like all other construction operations, attention to detail and quality of workmanship are major factors in reducing the amount of construction related cracking along newly replaced slabs.

The corner and edge cracks are about 1" to 2" long and are due to irregular finishing techniques and premature passage of construction traffic over the slab edges immediately after the side forms are stripped. In many cases, the new concrete was not finished flush with the existing concrete and protruding pieces simply broke off. After the side form along the shoulder was removed, a 2" lip was left. Construction traffic traveled over the unconfined lip and small pieces of new concrete were chipped off. This situation can be remedied by either: (1) leaving the side form in place until the shoulder has been repaired or (2) removing the form and building a small soil berm next to the unrestained shoulder edge to provide a gradual dropoff for construction traffic until the shoulder is repaired.

Transverse cracks were found at slabs that were poured when air temperatures exceeded 90 deg. F. The high temperatures caused transverse contraction cracks in the uncured concrete. Slabs should not be replaced when air temperatures are likely to crest 90 deg. during initial set.

Post-construction deflection measurements were conducted to determine the joint efficiency and level of load transfer of the new slabs. Deflections were obtained at the approach and leave end of each construction and new expansion joint (Table 7).

Table 7
Joint Efficiency

Joint	Deflection (x.001"0) Approach Edge	Leave Edge	Joint Efficiency
Construction #1	4.1	3.0	84%
Type A Expansion	4.7	3.9	91%
Construction #2	5.8	4.3	85%

Note: $$\text{Joint Efficiency} = \frac{(2 \times \text{Leave Edge})}{\text{Approach Edge} + \text{Leave Edge}}$$

The joint efficiencies of the construction joints exceed 84% which is excellent performance. This means that the 1 1/8" dia. dowels installed at the construction joints to tie the new slab to existing concrete are indeed providing excellent load transfer.

The joint efficiency of the new Type A expansion joints exceed 90%. This means that the new slabs have restored the expansion joints to good condition with excellent load transfer.

The deflection measurements indicate that the new pavement slab have structural capacity equal to or exceeding that of the existing, adjacent undamaged concrete. The new slabs should last at least as long remaining life of the existing 16 year old pavement.

A major deficiency of the full depth slab replacement was unsatisfactory rideability. The new slabs caused a rough ride that in many ways was worse than the ride provided by the old cracked pavement!

The roughness was caused by finishing the slabs longitudinally in the direction of traffic. The longitudinal drag causes a bump at the end of the slab which in turn caused the poor ride. Transversely finished slabs do not leave the bump and exhibit acceptable rideability. Therefore all future full depth slab re placement should be finished with a transverse dragging vibratory screed.

The roughness of the new slabs was measured using a 10' rolling straight edge. The straight edge is used to mark areas that exceed the NJDOT minimum roughness criteria of 1/8" in 10'. Twenty nine (29) slabs were measured with the straight edge. The measurements indicate that 20% of the newly replaced slab length exceeded the 1/8" in 10' roughness criteria. NJDOT roughness specifications require that new concrete pavement should not exceed more that 5% of the length as defective. Clearly the new slabs exceed the minimum 5% of length roughness criteria and the rideability is unsatisfactory.

The deficient pavement slabs were eventually restored to acceptable roughness levels through the use of diamond grinding.

It is recommended that as a matter of routine, diamond grinding should be used to restore rideabilty, reduce faulting and improve skid resistance of all new pavement after all new full depth slab replacement work. Although the combination of subsealing and full depth slab replacement restores structural capacity to the pavement, surface roughness and faulting still remains. Diamond grinding can be used to provide a smooth pavement with acceptable skid resistance.

It is estimated that based on the condition survey and deflection measurements, the new full depth slab replacement should outlast the existing pavement. The expected life of the new slabs should be at least 10 years. However, the slab life may be reduced due result of the dynamic, pounding action of trucks riding over the bumpy patches.

3. JOINT CLEANING AND SEALING

Joint sealers have remained in place for at least 6 months. However, in some areas the transverse expansion joint sealer has lifted out. The performance of the joint sealer is satisfactory. Joint sealing should last about 2 years before resealing is required.

The limited life of the joint sealer introduces the question of cost effectiveness. The total cost to reseal 17.3 miles of 3 lane pavement was in excess of $ 0.5 million or a cost of $ 30,000 per mile. Joint sealing may not be cost-effective when considering the limited performance life and questionable effectiveness of this strategy. There are indications that the joint sealer does not water proof the joints. Surface water has been observed flowing into newly sealed joint. Future inspections will indicate if joint sealing is a cost effective and prudent CPR strategy.

4. PARTIAL DEPTH SPALL REPAIR

The performance of the partial depth spall repairs after one year of traffic is highly unsatisfactory. 40 of the 46 spall repairs (87%) have cracked or crushed under traffic. The fast setting concrete used for the spall repairs does not resist the pavement expansion/contraction forces or the heavy truck loading.

It is recommended that partial depth spall repair not be used on future CPR projects. Damaged or cracked concrete pavement should be repaired by replacing with a new full depth patch. Partial depth repairs do not work.

5. LONGITUDINAL UNDERDRAINS

1 year after installation, the longitudinal underdrains to gether with the subsealing has halted pumping of the concrete pavement. Joints have been sealed and a new bituminous concrete shoulder has bee constructed thus limiting the inflow of water into the subbase. However there are still areas where surface water can infiltrate the subbase. For instance, rain storms during May 16, 1989 caused outflow of 135 gpm. from one Type X underdrain at Sta. 710+00 NB. Tipping buckets and a rain gauge will be installed later when transverse expansion joints and the concrete pavement shoulder joint have chance to open.

The Type X underdrains are designed to carry water from the pavement/shoulder joint thus limiting pumping of the slabs. The longitudinal underdrains are effectively removing water from the subbase and are limiting pumping and erosion of the subbase.

Based on the initial performance evaluation, it is estimated that the underdrains will be free drainning and remain unclogged for at least 15 years after installation.

6. PAVEMENT GRINDING

The pavement grinding along I-295, Sec. 1X noticeably reduced faulting. Pavement grinding is the CPR technique that is most noticed by the riding public. The major priority of motorists when riding down the highway is a smooth ride. The ride quality or roughness is how the public judges the success of a CPR job. The success of pavement grinding in removing faults along the I-295, Sec. 1X project and restoring smoothness to the new slabs on the I-295, Sec. 3F,4K,5K project indicates that pavement grinding is a most effective CPR technique. Pavement grinding reduces roughness to levels that are smoother than new pavement construction and should be specified on every future CPR project to insure the safety and comfort of the riding public.

Providing that the pavement does not resume pumping, the reduction in roughness caused by pavement grinding should last about 7 to 8 years.

H. ECONOMICS

The choice of whether to rehabilitate existing concrete pavements by resurfacing with bituminous concrete or using the various CPR techniques is based on traffic volume and economics. Resurfacing can be done with minimal lane closures. Lanes resurfaced with bituminous concrete can be reopened immediately after paving. Lanes can be temporarily closed with inexpensive barrels during resurfacing. Whereas, CPR techniques such as full depth slab replacement can require lane closures for up to 3 days. Ex pensive concrete "Jersey" barriers are needed to close off lanes overnight. Thus, resurfacing with bituminous concrete should be used on heavily traveled pavements where lanes can not possibly be closed overnight. CPR can possibly used on light to moderately traveled concrete highways where overnight lane closures can be tolerated.

Once the traffic related issues are resolved, the decision to select resurfacing or CPR is based on economics. Consider the following analysis comparing the potential cost of resurfacing with bituminous concrete versus CPR.

Assume: Subsealing and longitudinal underdrain work will be done regardless of either alternative therefore these costs will be ignored for comparison purposes. Resurfacing will be done on all three lanes. Fulldepth slab replacement requires work only in the slow lane.

Alternative No.1 - Bituminous Concrete Resurfacing

6" Bit. Concrete Overlay = $ 19.00 per LF
= $ 100,000 per lane mile

Temporary Traffic Control
with Barrels = $ 2.00 per LF
= $ 10,560 per lane mile

Total Cost for 3 Lanes = $ 110,000 mile

Alternative No.2 - CPR using Full depth Slab Replacement and Pavement Grinding.

Full Depth Slab Replacement = $ 24.00 per LF
(Slow Lane Only) = $ 127,000 per mile

Pavement Grinding = $ 10.00 per LF
(3 Lanes) = $ 53,000 per lane mile

Traffic Control using
Concrete Barrier = $ 60.00 per LF
(Slow Lane only) = $ 316,000 per lane mile

Total Cost of CPR = $ 496,000 per lane mile
= $ 94.00 per LF

Summary

Alternative No. 1
Bituminous Concrete Overlay = $ 110,000 lane mile

Alternative No. 2
CPR with Full Depth Slab Repl.
and Pavement Grinding = $ 496,000 lane mile

= $ 94.00 per LF

The preceding analysis indicates that CPR work is nearly 5 times more expensive than bituminous concrete resurfacing due the high costs of concrete barriers needed for overnight lane closures. However, the advantage of CPR is that damaged slabs can be selectively replaced whereas an existing concrete pavement must be resurfaced for the full length and width of a section regardless of whether slabs are damaged or not in order to insure continuity of the resurfaced pavement surface across all 3 lanes.

Using the costs developed above, CPR is more cost effective when less than 20% of the pavement length requires rehabilitation. Resurfacing is more cost effective when more than 20% of the pavement length requires rehabilitation.

Breakeven Length:

Cost of Resurfacing (per mile) = CPR Cost (per LF) x (Breakeven)

$ 110,000 = $ 94.00 per LF x (X)

Breakeven Length (X) = 1170 ft. = 20% of 1 mile

(1170/5280) = 22%

I. CONCLUSIONS

Six (6) CPR techniques were used on the Rt. I-295 section 3F, 4K & 5K project: slab subsealing, full depth slab replacement, partial depth spall repair, cleaning and sealing of joints, longitudinal underdrains and diamond grinding. With the exception of partial depth spall repairs, all the techniques were completed efficiently and performed well during the observation period.

Many of the partial depth repairs had failed after one year. These were made with fast setting patch materials and did not bond well to existing concrete. The longitudinal underdrains type "X" placed on approximately 16 miles of the project appears to be working satisfactory. However, Geocomposite edge drains (described and evaluated in a companion report on this project) were placed for a much lower cost ($8.00/feet savings) and appear to be performing as well as the more costly "X" drain.

Diamond grinding was extremely effective in improving ride quality on both reconstructed and existing pavement section.

J. RECOMMENDATIONS

Recommendations for each type of CPR technique employed on the I-295 project are provided after the description of the particular technique in this report (Section E). Therefore, only a few general recommendations based on information and experiences from this project will be provided in this section.

CPR operations such as full depth slab replacement requiring lane closures for more than 4 hours were protected with precast concrete "Jersey" barriers. Installation of the heavy "Jersey" barriers is a tedious and expensive operation requiring a crane, 2 or more flatbed trucks, and a crew of at least 10 laborers. Traffic control costs on this project were 20% of the total CPR costs.

CPR operations such as subsealing, joint sealing, underdrain installation and grinding which are dynamic and require temporary lane closures can be protected with a system of drums and barricades.

Protection of temporary lane closures with barricades or barrels is much less expensive than use of the heavy "Jersey" barriers. CPR operations should be designed so that lanes can be safely closed for less than 4 hours thereby permitting the use of less expensive drums and barricades.

It is recommended that accelerators such as calcium chloride be investigated for use in concrete for full depth slab repair to reduce the time that traffic control protection is needed. This will result in significant savings in the bid items for traffic control.

NJDOT RESEARCH LIBRARY
3 4310 00002 8756